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Energy Systems Group Annual Progress Report 1 January - 31 December 1983

Edited by
Gordon A. Mackenzie and Hans Larsen

Risø National Laboratory, DK-4000 Roskilde, Denmark
March 1984

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ENERGY SYSTEMS GROUP
Annual Progress Report 1 January - 31 December 1983

Edited by Gordon A. Mackenzie and Hans Larsen

Abstract. The report describes the work of the Energy Systems Group at Risø National Laboratory during 1983. The activities may be roughly classified as energy planning, development and use of energy-economy models, energy systems analysis, and energy technology assessment. The report includes a list of staff members, as well as their experience and areas of interest.

INIS Descriptors: DENMARK; ECONOMIC ANALYSIS; ENERGY ANALYSIS; ENERGY SOURCES; PLANNING; POWER DEMAND; RESEARCH PROGRAMS; RISOE NATIONAL LABORATORY; TECHNOLOGY ASSESSMENT

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1. INTRODUCTION

In 1983 the work of the Energy Systems Group (ESG) covered a wide range of activities, from organizing an international conference to conducting various assessment studies. The activities of the group cover the development of energy-economy models, energy planning, and technical and economic assessments of energy technologies and systems. The tasks are carried out either as basic R&D studies or under contract with various organisations in Denmark and abroad.

The studies undertaken are very often carried out in close collaboration with companies, ministries or international organisations, such as the Danish Ministry of Energy, the Danish Energy Agency, the Danish Environmental Protection Agency, the Commission of the European Communities.

The research and development activities in 1983 involved two postgraduate research projects. An ongoing project deals with the development of a model for the simulation of combined heat and power production. During the year a new postgraduate research project was initiated with the purpose of developing an energy rationing model for acute energy shortages. In addition to these two projects, work continued on the development of a method to incorporate uncertainties in the economic calculations for energy technologies was continued.

The DES-model which has been used in connection with Danish Energy planning for many years is continuously being updated and modified. The work on the energy modelling programme of the Commission of the European Communities in 1983 was centred around the macrosectoral model HERMES.

In conjunction with the energy modelling activities of the group an international conference on the Use of Simulation Models in Energy Planning was organised. The conference was sponsored by the Commission of the European Communities and Risø National Laboratory, and took place at Risø from 9th to the 11th May 1983.

The Energy Systems Group has for many years been deeply involved in Danish Energy Planning, in particular on a national basis. In 1983 the activities in this area have covered the participation in a study undertaken by the Danish Ministry of Energy concerning the space heating and hot water supply forms in areas of Denmark scheduled to receive neither natural gas nor CHP-generated district heating. The work for the Ministry of Energy has in addition comprised electricity demand forecasting, work in connection with Energy Review 83, and assessment of power plant economy - coal and nuclear. Finally one of the major undertakings of the group in 1983 has been the completion of a study initiated in 1982 on the long-term prospects - up to the year 2030 - of the development of energy-related technologies of importance to Denmark.

A number of assessment studies have been carried out under contract. The group has participated in a assessment of the technical and economic prospects for wind energy in the EEC countries. In collaboration with the Fraunhofer Institute in Germany a study has been carried out for the Commission of the European Communities on employment effects of energy conservation measures. A study of the cost effectiveness of various measures to reduce SO_2 and NO_x emissions has been carried out for the Danish Environmental Protection Agency. Finally a model to calculate the duration of emergency stocks during a supply crisis has been developed for the Danish Energy Agency.

During the year two guest researchers from Sweden and the U.S. have visited the group for two months each. Members of the group have participated in and presented papers at various conferences around the world. Moreover the group has participated in seminars in Hong Kong and Singapore on Danish Know-how and Technology on Energy and Pollution Control.

2. ENERGY PLANNING

During 1983 the Energy Systems Group was involved in a number of energy-planning activities in collaboration with the Ministry of Energy, the Energy Agency (Energistyrelsen), and the Environmental Protection Agency (Miljøstyrelsen). In addition to these activities, work was started on a new Ph.D. project.

2.1. Work for the Ministry of Energy

The Energy Systems Group has been involved in the energy planning activities of the Ministry of Energy for many years. ESG took part at many levels in the work for Energy Plan 81 (1), the most comprehensive energy-planning task carried out by the Ministry to date. Since the completion of Energy Plan 81 an effort has been made to update the analyses and projections and to follow up the work with deeper investigations into various subjects. Some of the major projects of this kind in which ESG participated are described below.

2.1.1. Energy Review 83

According to law, the Minister of Energy is required to present a review to parliament at regular intervals on the supply and consumption of energy in Denmark. The latest review of this kind, Energy Review 83 (ER 83), was presented in the spring of 1983, and a status report was published later (2), (3).

The Energy Systems Group participated in a number of working groups set up by the Ministry for the preparation of this review. These include working groups on the projections of the future prices of coal, oil and natural gas, the price of the nuclear fuel cycle, the investment costs of coal-fired and nuclear power plants, and projections of the future electricity demand.

One of the major tasks was the updating of the energy planning data of the DES-model (see below Section 4.1) and the calculation of a revised basic scenario of the Danish Energy system using this model.

2.1.2. Economic assessment of nuclear power in Denmark

During 1983 ESG participated in working groups set up by the Ministry of Energy to revise earlier studies on the economic assessment of the introduction of nuclear power in Denmark. These included working groups for price forecasts for steam coal, the nuclear fuel cycle, and the investment cost of coalfired and nuclear power stations.

The generating costs of electricity from a 900-MW light water reactor are compared with the generating costs from other base-load producing units, especially a 600-MW coal-fired condensing unit. These costs are calculated as discounted levelised costs in real terms per kWh fed into the grid.

The impact of nuclear plants on the Danish electricity-generating system is studied using the DES-model. Like the study for Energy Plan 81 cash flows of the electricity generating system are calculated for a period of about 30 years for development plans with and without nuclear plants.

In another analysis with the DES-model, nuclear plants are introduced one by one into the generating system for a given year.

The running costs of the system are calculated by the model on various assumptions of system capacity and demand for electricity and CHP, so the variations of these costs can be compared to the variations in capital costs.

In connection with these studies ESG participated in the Working Group on the Economics of the Nuclear Fuel Cycle set up by the Nuclear Energy Agency under the OECD.

2.1.3. Area IV

ESG is currently involved in a study of the space heating forms in the so-called area IV, the parts of the country scheduled to receive neither natural gas nor CHP-generated district heating. The work consists of several tasks subdivided into two levels.

At the micro-level the single supply technologies are evaluated with regard to profitability and, to a certain extent, foreign exchange and employment. At this level ESG has mainly played an advisory role.

In the work at the macro-level ESG participats more actively. The tasks consist of the mapping of the heating demand and the local energy resources, a series of "macropictures" of the consequences of different policies and the evaluation of the policy instruments.

The first task at the macro-level is now completed. A list of all towns and villages in Denmark with more than 200 inhabitants has been made on the computer at Risø. For each town the following data are listed: the number of inhabitants, the town's status in the heat supply planning and numbers for the energy districts in the energy atlas database which correspond to the town. The latter database is a result of the Danish heat supply planning and contains heating demand data disaggregated geographically and with respect to heating forms and building types.

With the help of the list of towns the heating demand has been calculated for each county in Denmark. The heating demand is disaggregated into the following village types:

village	1a:	1000-4999	inhabitants	with	district heat
"	1b:	"	"	without	"
"	2a:	500- 999	"	with	"
"	2b:	"	"	without	"
"	3 :	200- 499	"	without	"

The result for the whole country is shown in Fig. 2.1.

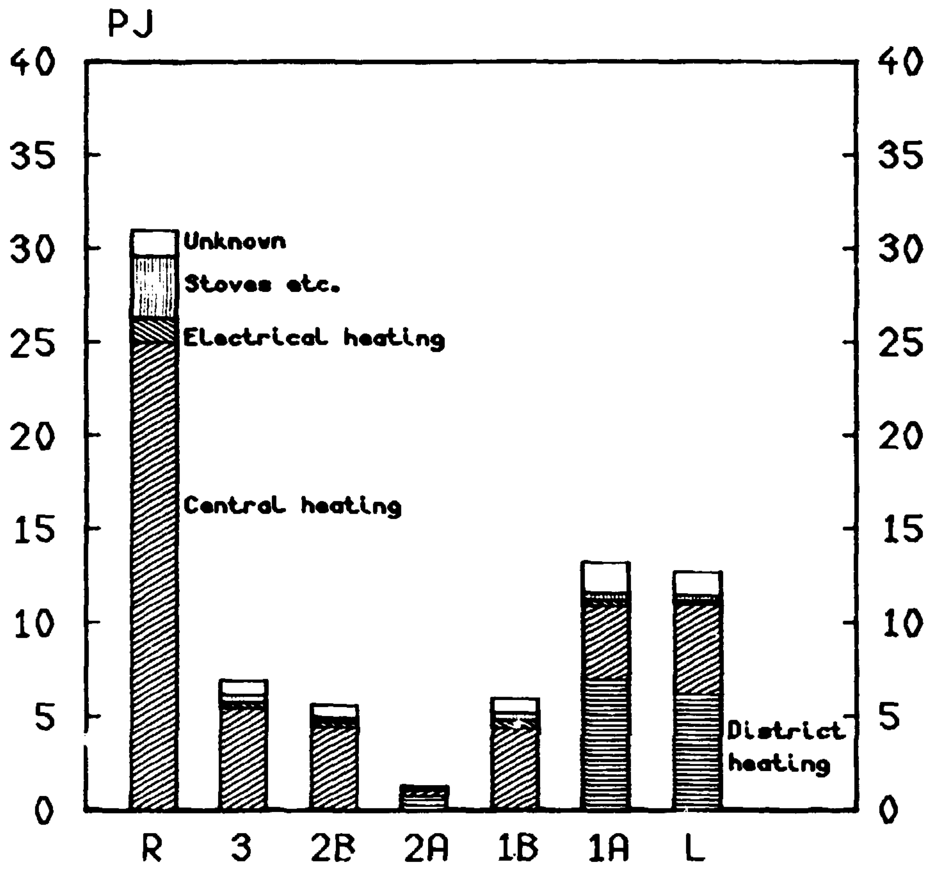

Fig. 2.1. Distribution of heating demand in area IV with respect to town size and heating form.

Besides the town categories 1-3, Fig. 2.1 also includes rural areas (R) and some towns (L) with more than 5000 inhabitants. A list of the local energy resources (livestock waste, straw, wood, and refuse) has been created on the computer at Risø. The resource data is listed for each municipality.

The remaining task in 1984 is to connect the heating demand in area IV with the renewable energy resources via the technologies discussed at the microlevel. Different "macropictures" are now being constructed and will be evaluated according to overall criteria such as: profitability, foreign exchange/employment, maximum use of local resources, environment, and robustness/flexibility.

2.2. Security of supply

In order to study the consequences of disturbances in the supply of energy from abroad, a model has been created which describes the use of energy in Denmark. This work may be regarded as a continuation of similar work carried out by ESG some years ago in the wake of the oil crisis in 1973 (4).

The present work was initiated by The Danish Energy Agency, one of whose tasks is to estimate counter-measures for minimising the consequences of decreasing supplies of energy. These counter-measures may be, for example, substitution of one fuel by another, or restrictions of the use of energy. The benefits of fuel storages may also be studied.

The Energy Agency felt a need for a computerised model which would permit reasonably fast and consistent calculations to be made, taking into account all sections of the community and all forms of fuel. A short description of the model is given below.

The basis for the model is a collection of statistical data on the use of various fuels and converted energy by different consumers, e.g. households, industry, and transport. The fuels may be coal, petrol, light fuel, natural gas, etc. and the converted energy: piped heat, electricity, and town gas. The consumers are aggregated in 28 sectors, and the energy is separated into 13 fuel types.

In order to simulate different counter-measures, the energy system system is provided with three types of data: normal energy consumption, consumption when critical fuels are substituted by non-critical ones, and energy consumption if restrictions are imposed on the consumers, the restriction being specified per sector or per fuel.

The model characterises the consequences of a given shortage of fuel import (or delivery) by the number of days a given fuel storage will support the consumption. The contents of the fuel storages may also be changed in order to study their influence.

The model incorporates data for the Danish energy system for 1982 (statistical data) and for 1985 and 1990 (energy plans), both with regard to normal consumption, and for estimated substitutions.

The model is run interactively on a computer and the main results may be routed to a line printer. Thus, it is easy to study a number of scenarios in order to investigate the consequences of certain counter-measures during a given crisis.

2.3. Effects of energy system changes on the emissions of SO_2 and NO_x

In 1982 an "Acidification Committee" (Forsuringsudvalget) was set up by the Ministry of the Environment to investigate the consequences of sulfur dioxide emissions and the costs of introducing flue gas desulphurization (FGD) at Danish coal-fired power stations.

In the meantime ESG has undertaken a project for the Environmental Protection Agency aimed at studying the cost-effectiveness of reducing the emissions of SO_2 and NO_x by measures such as energy conservation, increased efficiencies, and energy production with lessened environmental consequences.

For each type of measure a simplified economic assessment is made in which the costs of avoiding FGD are taken into account. These assessments are based on the official forecasts of energy demand and energy prices until year 2000 and existing studies of the various measures and technologies. The measures include insulation of buildings, increased efficiencies of heat transmission systems, e.g. district heating grids, renewable energy, natural gas fired CHP, and more efficient use of electricity etc. In many cases assumptions are made for energy savings and reduced emissions, while it is not possible to estimate investment costs. In these cases a concept of "critical investment" is used.

The study shows that avoided costs of FGD are small compared to fuel costs, and that few measures which are not included in the official energy planning are economically attractive. However, within the range of uncertainty, there is a considerable potential for reduced emissions by measures which are economically acceptable.

The DES-model has been extended with a module in which the emissions are calculated The model is used to calculate the economic and environmental consequences of the various measures during the period until the year 2000.

The study will be finished in spring 1984.

2.4. An energy rationing model for acute energy shortages

A Ph.D. project was initiated in May 1983 in collaboration with the Economic Institute at the University of Copenhagen with the main purpose of analysing the possibilities for the optimal allocation of scarce energy resources in the event of a short-term reduction in energy supply. The analysis involves the consideration of, for example, strategic reserves and rationing. It is planned that the result of the study will be a model which can be used to decide on the optimal allocation of energy resources according to a set of criteria defined by the user.

An energy rationing model must operate on a highly disaggregated level, and therefore detailed information is needed about the various sectors in the economy. The model will be built as an input-output model in which a social welfare function is optimized under given constraints by the method of linear programming. As the energy shortage is assumed to last a short period, the technical coefficients in the model can be assumed constant.

The work on the project during 1983 has consisted of studies of elementary input-output theory, Swedish energy-rationing planning and the formulation of a simple theoretical statement of the fundamental linear programming problem using a 2x2 sector model. In addition, some simple calculations have been carried out using a 3x3 sector model.

Further work on the rationing model will include implementing it on a computer, performing runs based on statistical material, incorporating energy imports and disaggregating the sectors of the model.

3. ENERGY TECHNOLOGY ASSESSMENT AND SYSTEMS ANALYSIS

3.1. Long-term prospects of energy technologies

A comprehensive study of the long-term prospects of energy technologies with relevance to the Danish energy sector was carried out for the Danish Ministry of Energy in the period mid-1982 to January 1984. The study was initiated as a follow-up to the Danish Energy Plan 81, issued by the Ministry (1).

The study deals with the period from 2000 to 2030. The period up to the year 2000 is covered by the official Danish energy planning, from where the projections for the year 2000 have been taken over and used as the starting point for the present study. The study was conducted by the Energy Systems Group. However, as the study covers a wide range of technologies, a number of special reports were prepared as supplements to the main report. Experts from other departments at Risø and from universities and companies around Denmark were involved in the study at this level.

In view of the major investments in distribution systems for natural gas and district heat to be made in Denmark in the period up to the year 2000, special attention is paid to energy technologies related to these distribution systems and to the electricity system. Emphasis is put on identifying and characterising the main trends and interdependencies in the development of en-

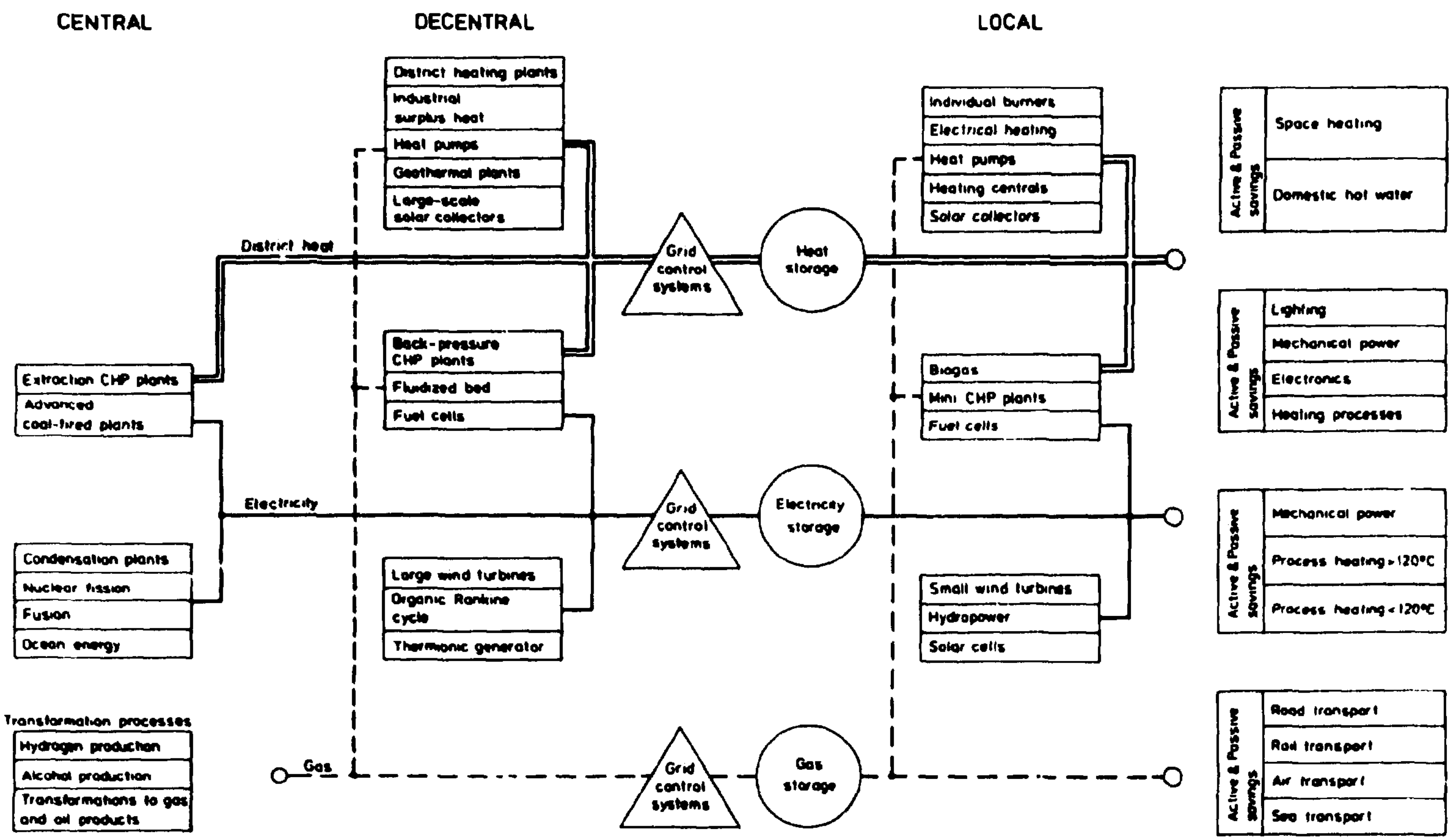

Fig. 3.1. Possible elements in the Danish energy system after the year 2000.

ergy technologies in the period 2000-2030, of which it may be important to take account at an early stage.

In Figure 3.1 an overview of the energy technologies which could pay a role in the Danish energy system in the period 2000-2030 is presented, together with the three main distribution systems. The figure embraces both energy-demand and energy-supply technologies. Storage facilities and control systems are also illustrated.

In the study a systematic analysis of the prospects for the individual candidate technologies included in the figure was carried out. A distinction is made between technologies already used in Denmark before the year 2000, technologies used in other countries and new technologies. The main emphasis in this study was put on new technologies presently at R&D level. As far as the technologies which are already known are concerned, the evaluation concentrated on possible improvements in efficiency and economy.

The technological development as such is strongly influenced by both the economic delevopment and that of society at large. This is also the case for the demand for energy and hence the possibilities for the introduction of new energy technologies into the system. For that reason the study had to embark on an evaluation of the economic development in Denmark up to the year 2030, as well as an assessment of the development of energy prices. The prediction of the economic development for such a distant future involves great uncertainties. For that reason two different scenarios were analysed in the study. As the most drastic changes in the energy system can be envisaged in a high productivity society both scenarios are based on an annual increase in productivity of 3 per cent. The difference between the two scenarios is that in the high scenario the productivity increase is used for consumption, whereas in the low scenario the productivity increase is used for reduction of working hours. From an energy point of view the high scenario results in a moderate growth in energy consumption up to the year 2030, while the low scenario results in a decline in energy consumption from 2000 to

2030 with the demand in 2030 down to approximately the 1980 level.

In order to identify sensitive areas and evaluate the possibilities for introducing new energy technologies, the two scenarios were simulated using the DES-model, described further in Section 4.1. The results of these calculations show that in both scenarios electricity will make up a relatively increasing proportion of the energy consumption in 2030.

Up to the year 2000 increased use of Combined Heat and Power (CHP) plants is planned in Denmark. As can be seen from Figure 3.2, the proportion of electricity produced on CHP plants in both scenarios is expected to decline from 2000 to 2030 leaving room for new electricity-producing technologies. The most sensitive area identified in the study is space heating. In Figure 3.3. the net energy consumption for space heating is shown for the two scenarios together with the expectations for the year 2000. Especially in the case of the low scenario the proportion of piped energy for space heating (natural gas, district heat and CHP) is very high, leaving no possibilities for further expansion; a reduction in piped energy might even be necessary. Comparing Figures 3.2 and 3.3 it can be seen that an increased ratio between electricity and heat in CHP plants, making use of advanced topping processes, could be a possibility.

The purpose of this study was to identify the characteristics of the more promising energy technologies in the period 2000-2030, with emphasis on those technologies which, in an uncertain future, represent robust solutions with a high system efficiency, and to suggest measures which should be taken at an early stage in order to develop an energy system which is able to accommodate such new technologies in due course.

Among the main findings of the study it can be mentioned that, due to the high energy prices anticipated in the study, efficiences are expected to be improved during the period for both demand and supply technologies. Similarly, increased use of indigenous resources, waste heat, etc. is expected, leading to a higher complexity of the energy system.

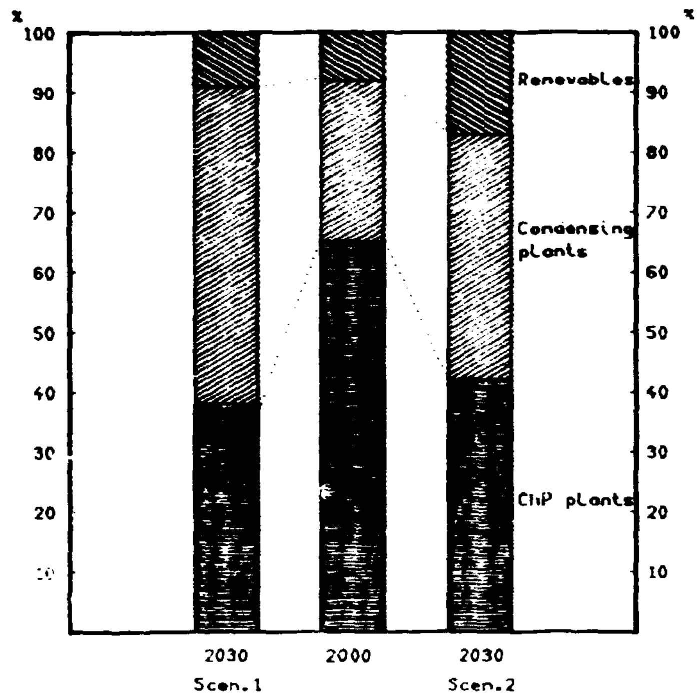

Fig. 3.2. Share of electricity produced by renewable sources, condensing power plants and congeneration plants

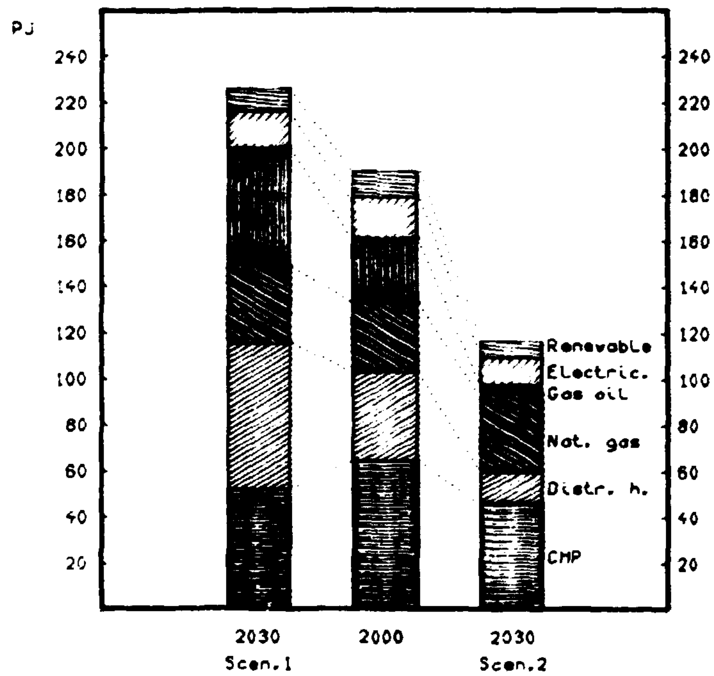

Fig. 3.3. Net energy consumption for space heating

It was found that the development and use of sophisticated electronic equipment and energy storage facilities to regulate the shape of the demand curve must be encouraged as these can lead to higher flexibility in the future system. As an example, the introduction of varying energy sources as wind energy and base load plants such as nuclear power are both facilitated hereby.

Care must be taken, especially in the space heating sector, as the market for piped energy could very well stagnate in the beginning of the next century.

3.2 Uncertainties in the economic calculations for energy technologies

As the result of a two-year research project a model has been developed to take into account uncertainties in economic assessment of energy technologies. The model displays uncertainties as probability distributions for economic quantities such as the present value of lifetime costs of applying the energy technology and an effective net energy price as produced by the energy technology.

Data for the economic assessment can at present be specified as uncorrelated probability distributions in the form of arbitrary histograms. The model calculates the probability distribution of the economic quantity being considered. This yields information on the economic risk related to the projected energy system in terms of uncertainties given as data.

The model is intended to be used by decision makers as a tool for evaluating economic consequences of the development of particular energy technologies.

A report on the model was issued in April 1983.

3.3. Employment effects of energy conservation measures in EEC countries

In 1983 ESG took part in a European study of the employment effects of energy conservation as a subcontractor for the Fraunhofer Gesellschaft, Institut für Systemtechnik und Innovationsforschung, Karlsruhe, West Germany. The study is funded by the Commission of the European Communities (DG XVII).

The study includes the impacts of changed energy flows and investment structures on production, employment, income and imports. The impacts are calculated for various branches or sectors of the economy, differentiating domestic production and imports, final and intermediate consumption as well as changes in gross and net production. The analysis takes into consideration the specific situation of the each country analysed, such as:

- market potential and energy efficiency of the studied technologies
- foreign trade of fuels and the analysed capital goods
- domestic interrelations of the economy and
- the national levels of labour productivity.

The impacts are analysed mainly using input-output techniques based on standard input-output tables available for eight EEC countries.

The following technologies are studied for Denmark: insulation of dwellings, heat exchangers in industry and commerce, construction and extension of CHP generation, solar hot water systems, and biogas installations.

The work consists of three major tasks:

- projections of the market potentials in the years 1990 and 2000 for these technologies, and the potential energy substitutions, investments and operation costs
- interviews of firms that are producers or dealers to collect data on the input structures of the production and operation of the technologies

- compilation of the necessary statistical data on the development of prices, imports, exports, wages, employment, productivity, and operation surpluses since 1975 at branch level corresponding to the 1975 EUROSTAT input-output tables.

The study will be completed in 1984.

3.4. Prospects for wind energy in the European Community

In March 1981, the Advisory Committee for Program Management for the CEC's solar energy programme initiated a study of wind power. The Energy Systems Group was awarded a contract to carry out part of the study, namely the assessment of the technical and economic prospects for windpower in Denmark.

The study was completed in 1983. The contractors from the 10 countries involved have reported the national data and findings to the coordinator of the study who is about to publish the final report.

4. ENERGY ECONOMY MODELS

4.1 The Danish Energy System Model - DES.

The DES-model was developed to calculate the total Danish energy demand and the associated costs. The model consists of modules for a number of subsystems of the energy system with suitable interface variables which allow the model to be used for partial as well as comprehensive studies of the energy system. Each module includes basic data and submodels of varying complexity, ranging from simple assignments to a simulation model for electricity and CHP.

Given a set of forecasts for the demand for useful energy and a development plan for the conversion and distribution system, the model calculates the annual primary energy requirement together with the fuel costs, and the costs of investments, operation, and maintenance for the energy system.

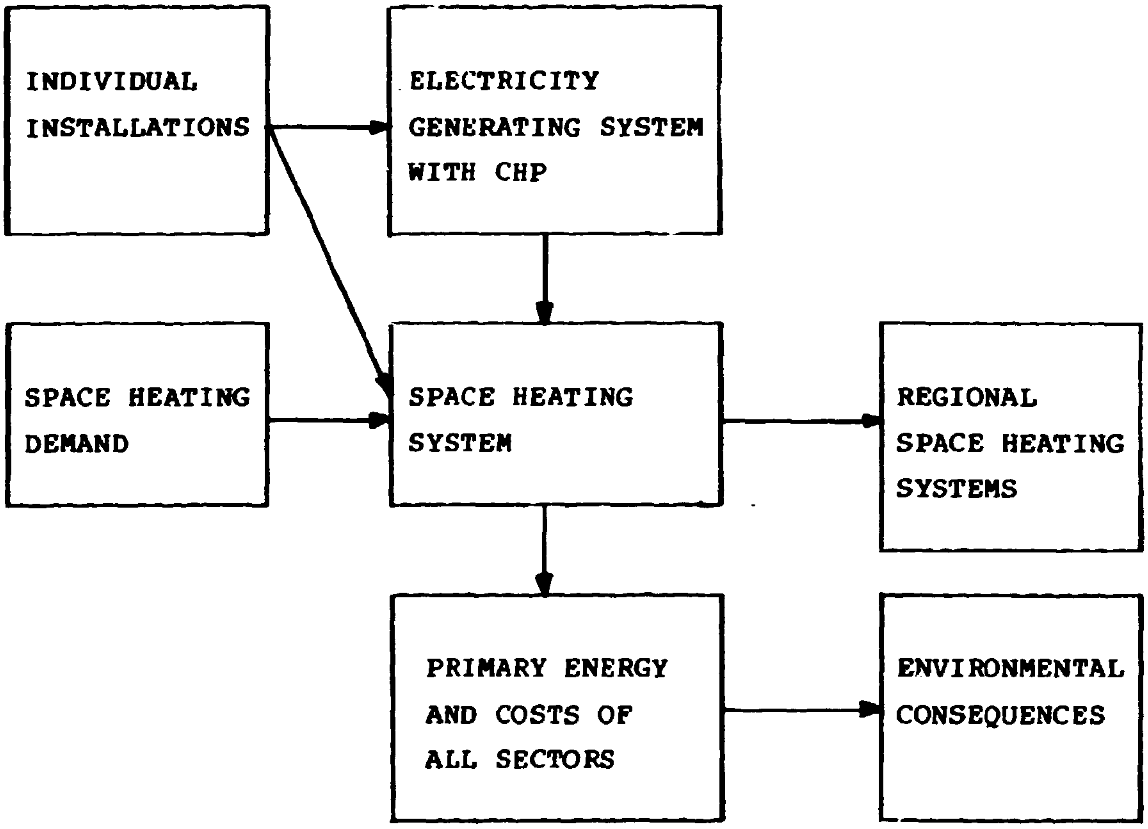

Fig. 4.1. Modules of the DES-model.

The DES-model has been used by ESG for several studies of the Danish energy system during the last 4 years. These include the evaluation of the various energy consumption scenarios and the energy supply system defined in the Danish Energy Plan 81, as well as partial studies of the Danish energy system.

In 1983 the model was used for several studies. Scenarios describing the entire Danish energy system were calculated for the

Energy Report 1983 (see Section 2.1.1) and for the study of the long-term technological development.

The database for the electricity generating system and the calculations of the energy requirements of the power stations were used by the Danish Environmental Agency as a basis for the calculation of sulfur dioxide emissions from power stations in the period 1980-2000 for the Acidification Committee (Forsuringsudvalget).

Partial studies of the Danish energy system by the DES-model were included in the studies of the energy supply planning for "Area IV"* for the economic asssessment of the introduction of nuclear power in Denmark (see Section 2.1.2), and for the study of the reduction of SO_2 and NO_x emissions (see Section 2.3).

One of the main developments in 1983 was the addition of the Environmental Consequences module which includes emission factors for SO_2, NO_x, CO and particles for each fuel type and each type of conversion. Given the primary energy demand in sectors relevant for environmental analysis, the emissions are calculated together with the costs in each sector.

Further developments in the DES-program during 1983 were the following:

- All variables (or accounts) are characterised by a four digit number, and in order to use these systematically when large system are modelled, the original maximum of 2999 has been increased to 9999. If less than about 1200 active variables are used then all information may be contained in the fast memory of the computer (Burroughs B7800). If the number of active variables is greater, then disk storage must be

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*Area IV is the name given to parts of Denmark not supplied by natural gas or CHP heating.

used. This means a significantly slower performance of the program although a considerable effect has been devoted to optimising the transfer of data between core and disk.

- The original DES-handling system was devised for a maximum time period of 40 years. On several occasions a need has been felt to increase this period. A facility has been introduced which allows the user to move data from a given 40-years period to another arbitrary period, also of 40 years. Thus any length of time may be considered.

4.2. SIMULACHRON - a simulation model for CHP production systems

In collaboration with the Electric Power Engineering Department at the Technical University of Denmark a Ph.D. project has been carried out. The principal aim of the research has been to produce a detailed model describing technical and economic aspects of a national CHP system. This comprises condensing, extraction, and back-pressure power plants, district heating boilers, and day-to-day heat storage facilities. Transmission systems for heat and power are also modelled.

To simulate the hour-by-hour operation of the system the model has been implemented on a computer. Test-runs of the computer program, called Simulachron, covering 48 time steps and some 30 plants have been performed.

The main parts of the model are shown in Fig. 4.2. As can be seen, electricity from wind generators can also be included in the simulations.

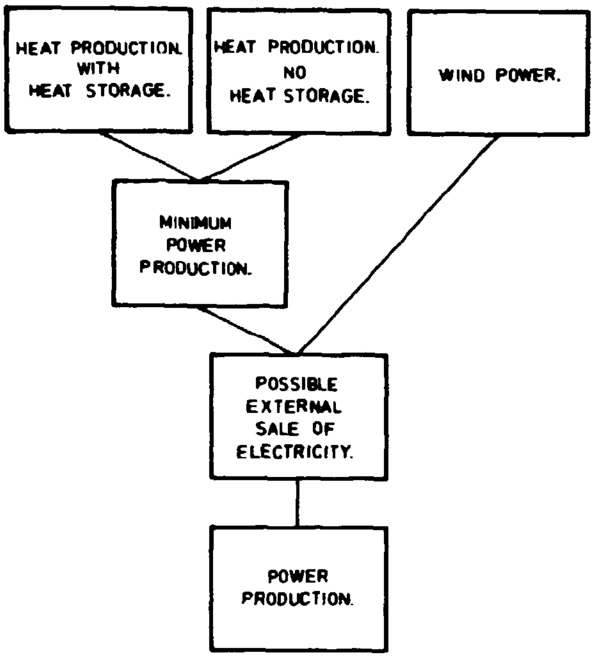

Fig. 4.2. Main parts of computer model

Some results from simulations of 3 small examples with only one district heating area will be given below. The 3 cases simulated by the Simulachron model consider the some demands for heat and power, but satisfied in 3 different ways:

Case 1: Electricity is produced by three power plants, a base load, medium load, and peak load plant. Heat is produced by a district heating boiler fired by fuel oil.

Case 2: The medium load condensing power plant is converted into an extraction power plant. The district heating boiler is still present.

Case 3: The system is equal to the one described for case 2, but a heat storage facility is added.

Figure 4.3 gives the power production for the three cases along with the limits which are set by the heat production. In cases 2 and 3 the heat production is proportional to the minimum power production from the CHP plant. By comparing cases 1 and 2 it is seen that the heat production at the medium load extraction

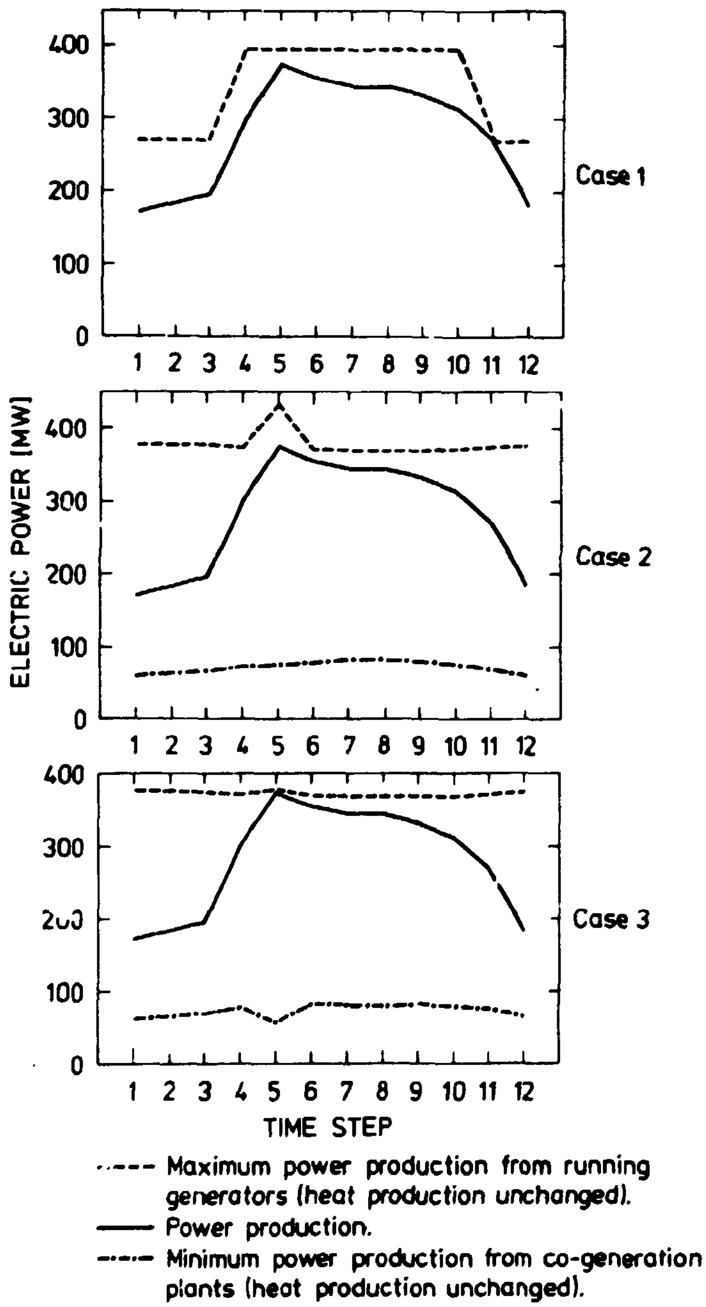

Fig. 4.3. Limits on power production set by heat production. In case 1 there is no CHP production.

plant reduces its maximum power production and that the peak plant therefore has to be started in time step 5 where the power demand is at its maximum. Moreover, by comparing cases 2 and 3 it is seen that the heat storage facility in case 3 is operated so that the heat production in time step 5 is reduced just enough to make it unnecessary to start the peak load plant.

During 1983 the model has been improved in various ways, e.g. the speed of computation has been increased. Moreover the reliability of results from realistically big examples has been tested. The documentation of the work is completed and will be published in 1984.

4.3. European Commission energy-economy models

The Energy Systems Group is responsible for the Danish implementation and application of four separate models as part of the energy modelling programme of the Commission of the European Communities. These consist of the medium-term energy demand model, the long-term energy demand model, the energy-flow optimisation model and the macrosectoral model.

The first three of these models are implemented in Denmark and have been used in conjunction with the CEC's programme for a number of years.

During 1983 the work within the national teams for the CEC models was concentrated on the development of the macrosectoral model, HERMES, The status of this project is described below. It is expected that work on updating and application of the other models, in particular the long-term energy demand model MEDEE3, will be resumed in 1984.

The macrosectoral model, HERMES, is a multinational macroeconomic model that focuses on energy-economy interactions and has a forecast horizon of 5-7 years. A national model is being built in each of the EEC member countries and all of them will be interlinked by a system of bilateral trade flows. While the national models are being developed by national teams, the trade system will be drawn up by the Commission of the European Communities.

In 1982 the work was centred on the estimation of the consumption and energy substitution parts of the model. Work on the estimations was continued in 1983, this time concentrating on the parts of the model concerned with production and prices and incomes.

For the production part, different specifications of the production function were tested. The specification which was finally chosen is a nested Cobb-Douglas/CES production function. Regarding the controversy of complimentarity or substitutability between energy and capital, the conclusion of this study is that clear complimentarity exists between the two. This conclusion is in agreement with results obtained for the other EC countries.

A number of different effects on wage formation were tested for the prices and incomes part of the model. The main conclusion of the study is that, for Denmark, the wage formation is adequately described by a Phillip's curve, that is relative changes in the nominal wage rate are determined by the level of unemployment and the rate of inflation.

The work programme for 1984 includes the final determination of all the parameters of the model and the first simulation experiments to test the model.

4.4. Databases

An important task in most energy planning projects is the collection and processing of statistical data.

At present ESG has direct access to the following databases:

1) The Danish Statistical Office (DS) National Accounts Department's Input-Output tables for 1966-80 classified into 117 branches, 66 consumption groups, and 9 final use categories.
2) DS's energy balances classified according to 117 branches and 23 energy types for 1966-80.
3) DS's investment figures distributed on investing branches classified into 51 branches and 4 types of investment for 1966-80.
4) DS's employment data classified into 117 branches and 5 types of employment for 1966-80.
5) The Danish district heating system consisting of data for building area, building use and heat installations for each municipality given from the building and dwelling register (BBR), and published or estimated data on capacity, heat supply, and fuel consumption for each district heating company.
6) The Energy Atlas, as mentioned in Section 2.1.3, consists of data for the number of buildings, the utilized area, and the heating demand for each town or village in Denmark. The data are disaggregated into six categories: single-family houses, multi-family houses, offices, industry, institutions and weekend cabins. For each of these types the number of buildings with different heating forms are given: district heat, central heating, electrical heating and paraffin stoves.

The above-mentioned databases are complemented by the addition of statistics from the Danish Energy Agency (ENS) and the Danish Association of Electricity Supply Undertakings (DEFU) for energy and electricity for the years 1966-82.

5. RISØ INTERNATIONAL CONFERENCE ON THE USE OF SIMULATION MODELS IN ENERGY PLANNING

In May 1983 a conference on the use of simulation models in energy planning was held at Risø. The conference, which was organised by the Energy Systems Group and sponsored by the Commission of the European Communities, was held in the spring of 1983 in order to coincide with the 25th anniversary of Risø.

The aim of the conference was to bring together scientists, economists, energy planners, and others with an interest in simulation models and the ways in which they can be used in energy planning. The application aspects were stressed in the call for papers in the hope that this would encourage contributions which concentrated on the actual use of models. This resulted in a wide selection of papers covering the use of models of many types in a variety of contexts, although the majority of contributions dealt with national energy planning.

The papers were organised into three groups, corresponding to the conference sessions in which they would be presented: Global and Multinational Studies, National Energy Studies, and Sectoral Energy Studies.

The total number of papers presented was 35, of which 7 were invited or "keynote" papers. The closing session took the form of a panel discussion in which the invited speakers and the conference chairman, Dr. Wolf Häfele, presented their conclusions, whereafter the discussion was opened to contributions from the other participants.

A number of interesting points were raised in the discussion. It was agreed that simulation models are extremely useful tools for energy planning, for a number of reasons. Model calculations are always subject to uncertainty, because of the uncertainties inherent in the data and the assumptions on which they are based.

Simulation models are particularly valuable in that they can be used to communicate the meaning and significance of such uncertainties. More attention should be paid to the communication between analysts, model users and decision makers so that the maximum use can be made of simulation models.

Another point which was made was that simulation models were well suited to taking into account the environmental effects of energy production, and that this should be encouraged.

Judging by the response to the conference, the number of papers presented, the participation and the positive comments received, we may conclude that the conference was successful in its aim of providing a forum for the discussion of the latest applications of models in the field of energy planning.

6. PUBLICATIONS AND LECTURES

6.1. Publications

P.S. Christensen and P.E. Grohnheit, "The DES model - a simulation of The Danish Energy System". The Use of Simulation Models in Energy Planning, Proceedings of Risø International Conference 9-11 May 1983. Risø National Laboratory.

J. Fenhann "Wind power in Denmark" Wind Energy, Proceedings of EC Contractors" Meeting Held in Brussels, 23-24 November 1982. W. Paly and W. Shnell (eds.), D. Reidel Publishing Company, 1983.

P.E. Grohnheit "Indicators of heating efficiency in Denmark". Workshop on Residential Energy Use, Proceedings. C. Zanantori (ed.) Joint Research Centre Ispra, Italy 14-16 June 1982 (SA. A1.03.17.83.04) p. 39-50.

H.V. Larsen and P.S. Christensen "Simulachron, a model for a national power system including CHP". The Use of Simulation Models in Energy Planning. Proceedings of Risø International Conference 9-11 May 1983. Risø National Laboratory.

L.H. Nielsen "Model til behandling af usikkerheder i økonomiske vurderinger af energiteknologier" (Model for the treatment of uncertainties in economic evaluation of energy technologies) Risø-M-2390, Risø National Laboratory, 1983.

G. Vogel and T. Jørgensen, P.E. Grohnheit and N. Kilde, E. Petersen (Danish District Heating Association) (Danish Boiler Owner's Association) "Indpasning af små og mellemstore kulanlæg i det danske energisystem" (Introduction of small and medium-size coal installations to the Danish energy system). Kulorientering 17. Danish Boiler Owners' Association, Risø National Laboratory and Danish District Heating Association, February 1983.

6.2. Lectures

J. Fenhann "Renewable energy in Danish villages and rural areas". Third International Conference on Energy for Rural and Island Communities, Inverness, September 1983.

Poul Erik Grohnheit and Peter Skjerk Christensen "The Danish Energy System and the Efficiency of Combined Heat and Power" Paper presented at the Workshop on Energy System Analysis, Modelling and Application. European Institute for Advanced Studies in Management, Brussels 14-16 March 1983.

P.E. Grohnheit, "Introduction of small and medium-size coal installations into the Danish energy system". IEA Coal Research, Economic Assesment Service. Technical meeting, Risø 14 June 1983.

H. Larsen "Energy Systems Analysis - Methods and Examples" Symposia on Energy and Pollution Control, Singapore and Hong Kong, March 1983.

7. STAFF

Leader:

Hans Larsen M.Sc. (DtH*), Ph.D. (DtH)

Graduated in 1970 from the Technical University of Denmark as M.Sc. in Electrical Engineering. 1970 postgraduate student at Risø, Ph.D. in Reactor Physics in 1973. From 1973 to 1976 seconded to the OECD High Temperature Reactor Project, Dragon, at AEE Winfrith, Dorset U.K. 1976-80 at Risø National Laboratory working with systems reliability and reactor core performance. Heat at the Energy Systems Group from July 1980. Member of a number of national and international committees:

Advisory group on long-term energy planning - the Danish Ministry of Energy, European Commission ACPM on Energy Systems Analysis and Strategy Studies, Danish National Committee of World Energy Conference, reference group on energy planning for the rural areas in Denmark - the Danish Ministry of Energy, steering group for solar energy R&D - the Danish Ministry of Energy. In 1983 involved in project on long-term prospects of energy technologies and chairman of programme committee for the International Conference on The Use of Simulation Models in Energy Planning.

Deputy leader:

Poul Erik Morthorst M.Econ. (Århus)

Economist specialised in general energy planning and econometric forecasting. Research assistant at Institute of Economics, Århus University from 1976 to 1977. Joined ESG in June 1978. Main activities within ESG include general government energy planning, especially forecasting of electricity demand, and the implementa-

*The Technical University of Denmark

tion of the CEC medium-term model. Working on the economics of renewable energy and member of advisory group set up by Ministry of Energy to study renewable energy in rural communities. Took part in the organisation of the conference on the use of simulation models in energy planning and in the project on long-term prospects of energy technologies. Member of an internordic working group concerned with uncertainties in energy planning. Substitute member of the CEC working group on "Information on Energy" set up by DGXIII.

Permanent staff:

Frits Møller Andersen M.Econ. (Århus)

Economist specialised in computer modelling and econometrics. Worked as teaching assistant in the Institute of Statistics, Århus University and as economic planner in local government before joining ESG in May 1980. Main activities within ESG consists of the development, implementation, and use of econometric models for energy demand forecasting, in particular the development of the macrosectoral model.

Peter Skjerk Christensen M.Sc. (DtH)

Physicist with previous experience in reactor physics in the Reactor Technology Department, Risø, before joining ESG as a founding member. Activities within ESG include modelling of electricity and heat production and transmission systems, modelling of total energy systems, and maintaining an up-to-date knowledge of the construction and operation of power reactors and of the nuclear fuel cycle. During the last year primarily engaged in the study of the security of supply and the study of the long-term prospects of energy technologies.

Jørgen Fenhann M.Sc. (Copenhagen)

Physicist with mathematics and chemistry as subsidiary subjects. After 1 year of teacher training taught at high school and DtH. Since July 1977 worked on the CEC energy supply model EFOM, first with the Niels Bohr Institute, University of Copenhagen, and since November 1978 with ESG. Activities within ESG include energy studies involving windpower, long-range technological forecasts, energy for rural areas and energy statistics.

Poul Erik Grohnheit M.Econ. (Copenhagen)

Economist, before joining ESG worked with the Danish Buildings Research Institute (1969-71), as a town planning consultant (1971-72 and 1979-80) and on economic planning in local government (1973-79). Joined ESG in May 1980. Main activities within ESG include the development and the use of the DES-model, economic analyses of the electricity generating system and the space heating system, and other activities within the fields of energy economics and physical planning.

Niels Kilde M.Sc. (DtH)

Graduated in 1962 as chemical engineer with special emphasis on metallurgy. From 1962 to 1981 employed at the Danish Steelworks Ltd., Frederiksværk as deputy manager in the laboratory (1962-67), personal assistant to the technical director (1967-72), head of planning and implementation of new continuous casting plant and department manager for production (1972-77), and finally development and energy manager. Joined ESG in September 1981. Activities include long-term energy planning, coal technology and industrial energy use. Member of the Danish Energy Ministry's steering group for energy R&D in industrial processes.

Helge V. Larsen M.Sc. (DtH)

Graduated in electronic engineering in 1974 and subsequently worked as a university demonstrator at DtH and as an electronic engineer in industry. Joined Risø National Laboratory in 1976, engaged in computer modelling of radiation heat transfer in BWR fuel elements with the Reactor Technology Department. Later worked on Nordic project on modelling of district heating systems, based on Studsvik Energiteknik, Sweden. Currently developing a model for the simulation of power station operation.

Gordon A. Mackenzie B.Sc. (Edinburgh), Ph.D. (Edinburgh)

Physicist with a background in experimental solid state physics. First came to Denmark in 1974 to take part in neutron beam experiments then spent 2 years at Risø, 1976-78, on postdoctoral project supported by the British Science Research Council. After one year as lecturer in physics at Edinburgh University, 1978-79, returned to Risø as guest researcher in Physics Department. Joined ESG in February 1980 to work primarily on the MEDEE3 model. Activities within ESG during the past year have included continued work on MEDEE3, assistance on the environmental study using the DES model and organisation of the conference on the use of simulation models in energy planning. Other interests within the group include energy problems of developing countries and transport energy. In addition, took part in marketing and public relations activities for ESG and Risø, in the latter half of the year as a member of the interdepartmental Marketing Group set up under the Contract Office.

Lars Henrik Nielsen M.Sc. (Copenhagen)

Physicist with mathematics as a minor subject. Master's thesis described a model for a solar heating system with a central heat storage combined with a district heating system. Worked as high school teacher and teaching assistant at the University of Copenhagen during period of study. Joined ESG in August 1981 as research fellow, becoming a permanent staff member in 1983. Main activities include the assessment of energy technologies, taking into account uncertainty and the study of employment effects of energy conservation.

Ellen V. Pløger M.Econ. (Copenhagen)

Economist specialised in economic modelling and econometrics. Worked in the Danish Statistical Office on national accounts, energy balances and input-output models before joining ESG in November 1982. Main activities within the Group are the development and implementation of the CEC Macrosectoral Model (HERMES) and input-output analyses of energy consumption in industries.

Postgraduate Student:

Jesper Munksgaard Pedersen, M.Econ. (Copenhagen)

Graduated in 1983 from the Institute of Economics of the University of Copenhagen. Master's thesis on public investment criteria. Joined ESG as postgraduate student in May 1983 on a Ph.D. project concerned with analysing the possibilities of allocating scarce energy resources in an optimal way and constructing an energy rationing model.

Consultant:

Peter Laut, Professor, Engineering Academy of Denmark.

Visiting Researchers:

Tord Eng M.Econ. (Stockholm)

Economist from the Energy Systems Research Group at the University of Stockholm, Sweden. During a two-month stay at Risø, May-June 1983, participated in several ESG projects, particularly that on security of energy supply.

Douglas Hill Eng.Sc.D. (Columbia)

Engineer, leader of National Center for Analysis of Energy Systems at Brookhaven National Laboratory, U.S.A. Worked at ESG for two months, September-October 1983, in connection with long-term technological development. Contribution entitled "Effect of scale and quantity on the cost and performance of energy technologies" included in the Appendix to the report on the above study.

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8. REFERENCES

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